Shipboard Measurements of Surface Flux and Near Surface Profiles and Surface Flux Parameterization

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LONG-TERM GOAL

The long-term goal of this project is to understand the effects of surface waves on the structure of the marine atmospheric surface layer and surface flux parameterizations under a broad range of wind-wave conditions.

OBJECTIVES

This project is part of the High Resolution Wave-Air-Sea Interaction research initiative (HiRes). The objectives of this project are to characterize low-level atmospheric wind and thermodynamic profiles and variations, to understand oceanic and atmospheric large scale forcing that affects boundary layer properties, and to understand the role of measured wave field in modifying atmospheric surface fluxes.

APPROACH

Our work within this project consists of three parts: measurements, the subsequent data analyses, and mesoscale model evaluation/improvements. The ship-based measurement efforts include high-rate sampling of the turbulent field for direct covariance flux measurements, continuous sampling of the low-level wind profiles by the ship-based acoustic Sodar, rawinsonde measurements of the troposphere, a suite of mean variables for quantifying the low-level thermodynamic and dynamic fields, downward radiation, and sea surface temperature measurements. The data analyses will focus on the low-level surface layer properties and surface flux parameterization involving sea state parameters. In addition to evaluating current COAMPS, we will experiment with sea-state dependant surface flux parameterization in COAMPS, possibly in coupled mode.

Qing Wang is responsible for the overall project. Mr. Richard J. Lind worked on instrument preparation, calibration, and data sampling. Dr. John Kalogiros, an external research associate from National Observatory of Athens, Greece, worked on the data analyses.

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WORK COMPLETED

1. Evaluation and improvements of the NPS data collection system to be used in HiRes. In addition to the at-sea flux measurement system, we also successfully integrated the motion sensing system with the sodar sampling system so that ship motion was collected time-synchronized with the signal from the sodar system.

2. Participated in the shipboard HiRes pilot experiment May 31- June 6, 2009 on board R/V Robert Gordon Sproul near San Clemente Island, CA. The full suite of NPS instruments planned for HiRes, including the sodar, were tested during the pilot experiment.

3. The same set of instruments were again deployed in the same vicinity of the HiRes pilot experiment onboard R/V New Horizon during the NPS student cruise class between July 24 and July 28, 2009. Main effort during this cruise was to test on the performance of the sodar on a different ship although all other instruments were setup to collect data during the entire cruise.

4. Data quality checking, calibration of all ship-board measurements and development of routines for correction of fast turbulence data for ship motion effects using GPS, compass and accelerometer data.

5. Initial processing of all measurements including rawinsonde soundings, sodar profiles, turbulent fluxes, and mean meteorological and sea surface temperature measurements.

RESULTS

Characterizing atmospheric boundary layer and upper air vertical structure from rawinsonde measurements: Rawinsonde measurements were made 3-5 times per day during the HiRes pilot experiment in June 2009 as well as during the NPS student cruise class in July 2009. Examples of the vertical variations of potential temperature are shown in Fig. 1 where soundings from the same day are plotted together. These sounding profiles are indicative of the larger scale atmospheric forcing at the time of the experiment. On June 1 (Fig. 1a), the atmospheric boundary layer was well defined at around 600-700 m above sea level (ASL) with a relatively strong inversion above. This is the day we experienced moderate wind and wind driven surface waves. On June 4 and 5, however, the measurement area was dominated by the presence of a low pressure system aloft, resulting in much higher atmospheric boundary layer heights and rather weak inversions. As a result of the synoptic settings, the low-level troposphere had very weak wind of less than 5 ms^{-1} and hence rather weak surface wind waves. As the subtropical high pressure system settles well into the summer, the July boundary layer is characterized by shallow cloud-topped boundary layers with strong inversion at the top. The mid-level atmosphere above the boundary layer is also very uniform spatially.

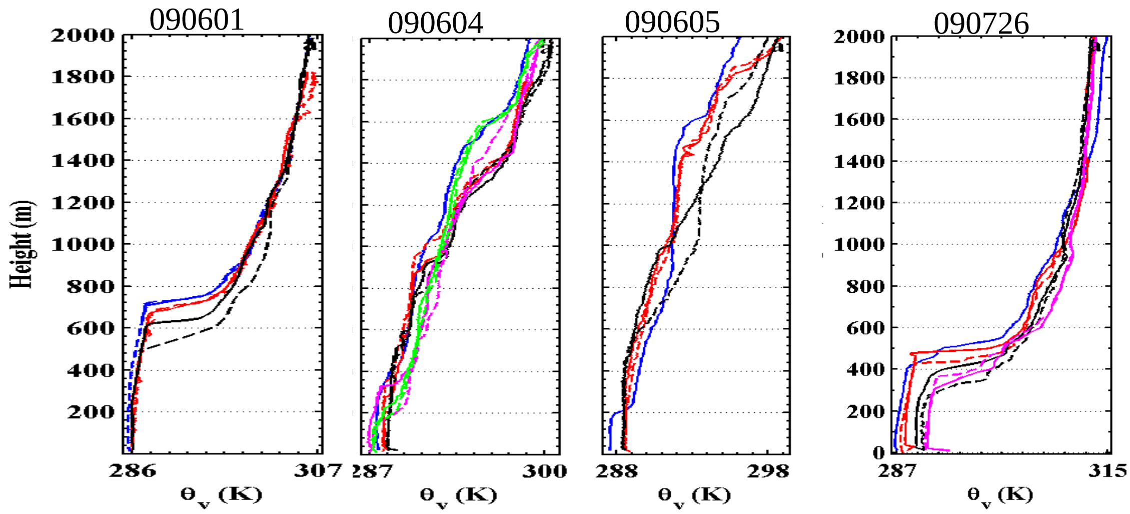

Figure 1. Vertical profiles of virtual potential temperature from three days during the HiRes pilot experiment in June 2009 and one day during the student cruise on the New Horizon in July 2009. Solid lines denote ascent soundings and dashed lines denote descent soundings when the rawinsonde descended with a deflated balloon and a parachute.

Sodar measurements onboard research vessels: One of our major efforts in FY09 was to configure and test the sodar for shipboard measurements in order to obtain continuous measurements of the low-level mean wind and turbulence profiles. Figures 2a-2c show examples of sodar measured profiles of the mean wind (uncorrected for ship motion) and vertical velocity variance, and backscatter intensity on board the R/V Sproul, respectively. Clearly, the sodar is capable of obtaining mean wind and turbulence information in the harsh environment onboard the ship. However, the substantial noise

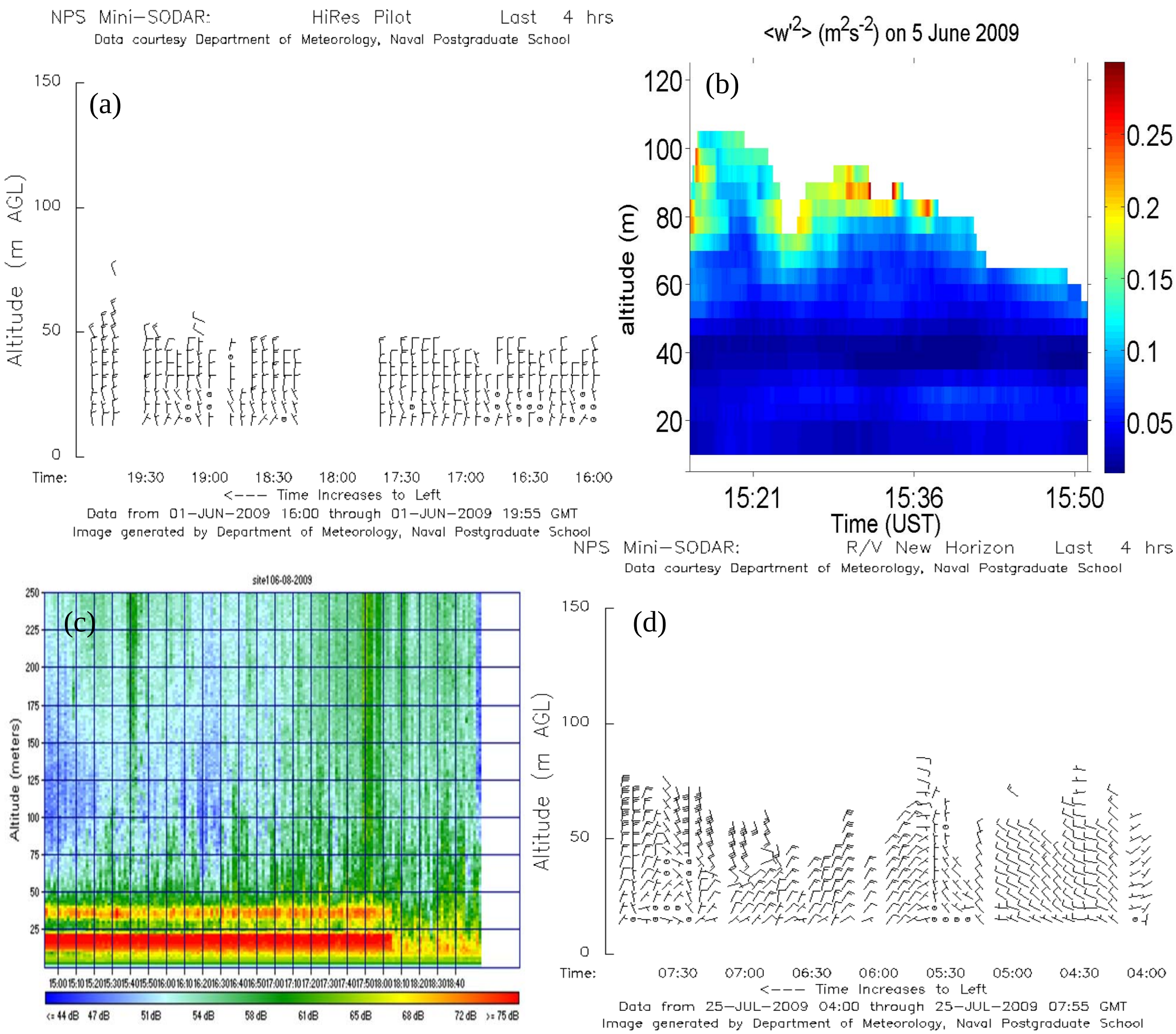

Figure 2. Shipboard sodar measurements of (a) uncorrected mean wind; (b) vertical velocity variance; and (c) backscattering intensity on board the R/V Sproul during the HiRes experiment and (d) uncorrected wind from R/V New Horizon during the July cruise.

level and the reflection from structures on the ship clearly limited the vertical range and accuracy of the measurements where the mean wind measurements were intermittent and were only up to about 50 m. In fact, the wind measurements from the R/V Sproul below 50 m were biased towards lower wind by the reflection of the WaMos tower nearby. This effect is seen clearly in Fig. 2c where the strong backscattering intensity near 20 and 40 m clearly diminished after the WaMos tower was taken down towards the end of Pilot experiment. Figure 2d shows the wind speed profiles from the July cruise onboard the R/V New Horizon where significant improvements of the wind measurements are seen without any superstructure close by. We conclude from these results that relocation of the NPS sodar away from the WaMos tower is necessary during the main experiment in FY10.

Fine scale variations of surface fluxes in the HiRes pilot experiment region: Measurements from the R/V Sproul during the HiRes pilot experiment revealed the strong spatial variability in mean wind, mean air and sea surface temperature, as well as in the resultant surface sensible heat flux (Fig. 3a), surface layer frictional velocity (u_* in Fig. 3b, representing momentum flux), as well as latent heat flux (not shown). Within the 20 km×20 km region shown in Fig. 2, the air temperature varied between 14.8^{o}C and 16.2 ^{o}C, while wind speed varied between 4.0 and 7.2 ms^{-1}(not shown). The region of larger frictional velocity corresponds well with the region of the highest wind speed at about 7 ms^{-1}. The high sensible heat flux in Fig. 3a was a result of higher wind speed (Fig. 3b) and cooler air temperature that increases air-sea temperature difference. The wave field was also measured by the multiple buoys deployed from the R/V Sproul, which will be used to examine the dependence of the measured turbulent field on the measured wave parameters.

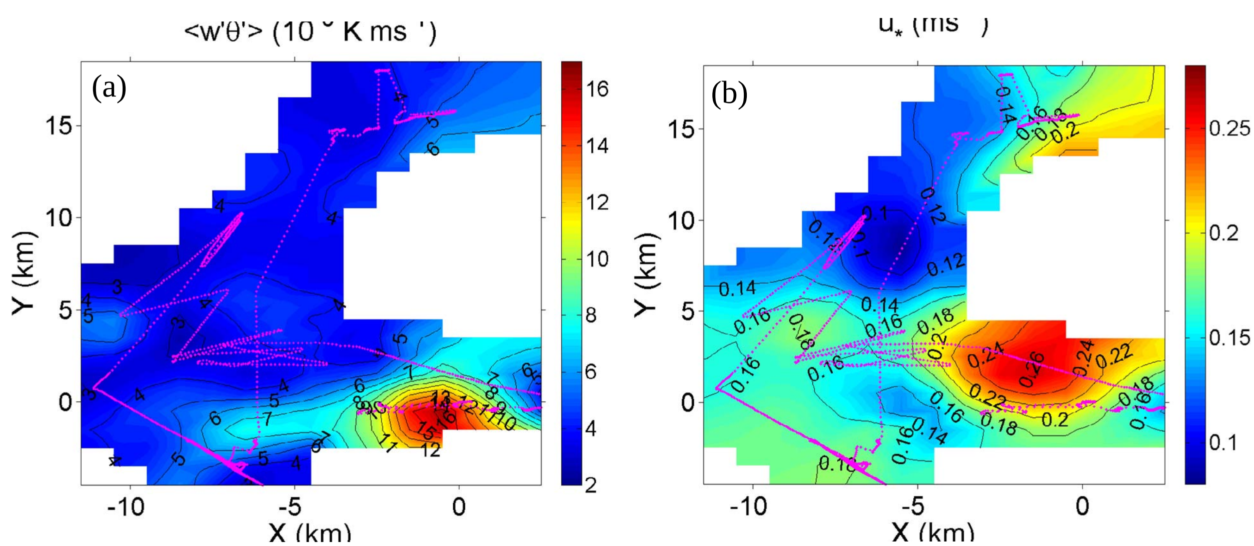

Figure 3. Spatial variation of (a) sensible heat flux and (b) surface layer frictional velocity from a portion of the ship track on June 5, 2009. The pink dotted line here denotes the ship track along which measurements were made and then interpolated to obtain the contour plots.

Uncertainty in sea surface temperature measurements: Sea surface temperature (SST) is a crucial variable in quantifying surface fluxes because it regulates the thermal stability of the surface layer. Ideally, SST from radiometric SST sensors is most desirable as it measures the skin temperature of the ocean surface which is most relevant to surface layer thermal stability. However, the accuracy of the radiometric skin temperature is on the order of the 1^{o}C, which is not sufficient for characterizing surface fluxes and their temporal and spatial variations. Figure 4 shows a comparison of SST from three sensors: a radiometric sensor (Wintronics, model KT15.82II, serial number 8513), an encapsulated thermistor measuring at a depth of 10 cm at the starboard side of the ship on the stern, and a hand-held water thermometer taking samples from the top layer of water (bucket SST). The measurements of the KT15 are also corrected by directly measured sky radiative temperature (with another KT15.82II sensor, serial number 8514) at the same time and location at an upward view angle. Figure 4 shows that the radiometric SST is consistently biased towards cooler SST although the correction by sky temperature does show slight improvement. The bucket SST seems to be consistent

with those from the thermistor at the side of the ship and these sensors also agree well with the SST sampled from the ship inlet by the ship. Although the thermometer measurements and the ship inlet water may be affected by the disturbances of the ship itself, their measurements seem to provide the correct sign of the air-sea temperature difference that is consistent with sensible heat flux measurements.

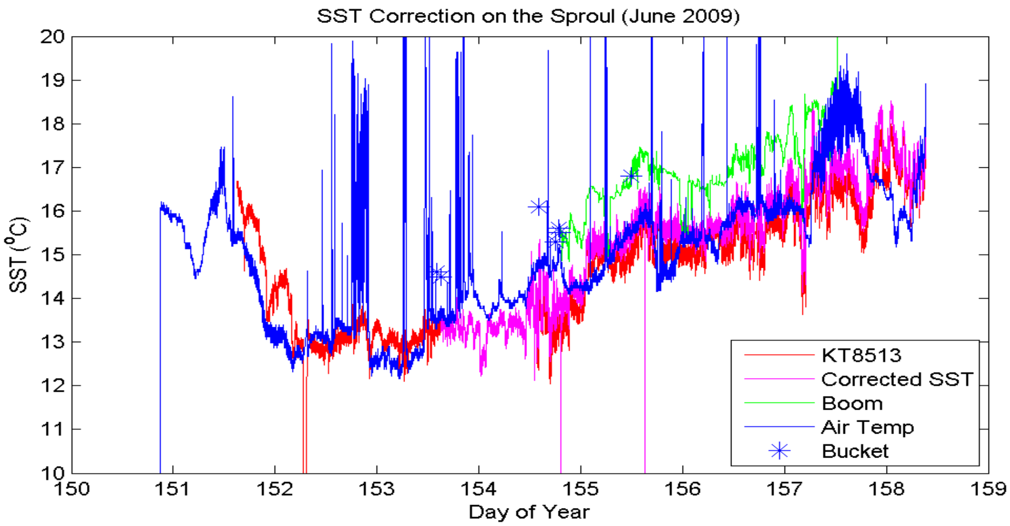

Figure 4. Sea surface temperature (SST) from several measurement motheds. The solid blue line is the air temperature measured at the same time as the SST measurements where the multiple spike in the measurements are likely results of the ship plumes.

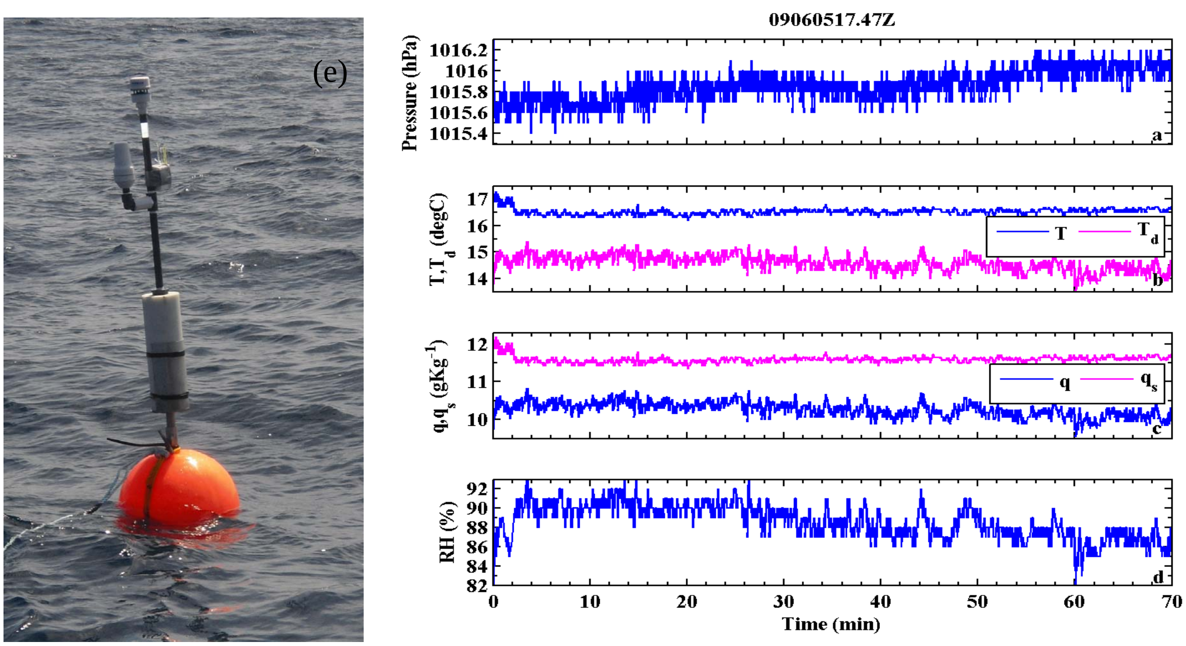

Figure 5. (a-d) Near surface variation of pressure, temperature and dewpoint temperature, specific humidity and saturation specific humidity, and relative humidity; (e) the small met buoy (SCRIPPS) with rawinsonde attached.

Water vapor vertical gradient at the sea surface: During the HiRes pilot experiment, we made the first attempt to examine the near-surface gradient of the surface layer by attaching the rawinsonde to a small met buoy (Fig. 5e) at about 1 m above the sea surface. It is seen in Fig. 5b that the specific humidity at 1 m height is on average about 1.5 gKg^{-1} lower than the saturation specific humidity at the same level. In fact, the relative humidity averaged to only 89% whereas the surface, which is only 1 m below this level, is often assumed to be saturated. Although large gradient is expected based on Monin-Obukhov similarity (M-O theory), very little observations in the past have shown the validity of M-O theory at altitudes less than 1 m. However, this is the layer where the air sea exchange happens most vigorously. Our trial measurement during the HiRes pilot experiment is encouraging and prompts us to make more in-depth analyses into this subject in future research.

IMPACT/APPLICATIONS

The two at-sea tests of the NPS measurement system for HiRes have been very productive. We are able to identify existing and potential measurement problems and also to test new measurement ideas, which are crucial to the success of the main experiment to be held in FY10. In the HiRes main experiment, near-surface gradients will be examined more closely by deploying tethersondes at several levels from a drifting buoy supported with a balloon, which can be spaced ~1 m apart with winds (~0.2 m without winds), with a maximum of four levels.

TRANSITIONS

The results of this project will potentially help to evaluate and improve the turbulence parameterizations of near sea surface atmospheric boundary layer in mesoscale models.

RELATED PROJECTS

Related project is the ONR High Resolution Wave Air-Sea Interaction DRI.